CONCENTRATING SOLAR POWER / ENERGY FROM WASTE HYBRID PLANTS - CREATING SYNERGIES

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Abstract

Tightening environmental legislation and landfill restrictions require waste management companies to increase their environmental sustainability. Several options exist to meet these targets, such as increased reuse and recycling. Modern Energy from Waste (EfW) plants are another option when they do not compete with recycling efforts; refuse derived fuels (RDF) fulfill this criterion. This paper investigates the hybridisation of EfW with concentrating solar power (CSP) plants focussing on CSP technology selection, integration concepts, synergies and suitable locations. A case study in Queensland Australia is provided to place the concept in a real world context.

For CSP technologies a high direct normal irradiance (DNI) is essential, typically >2,000kWh/m^2/a for a stand-alone plant. However, for CSP/EfW hybrid plants lower DNI levels, >1,700kWh/m^2/a, are acceptable as hybrid plants use some plant components jointly and can therefore lower the specific capital investment. In addition the hybrid technology allows the CSP asset to move closer to load centers, reduce new network costs and ensure fuel availability. A DNI >1,700kWh/m^2/a is still significant but many countries, such as Australia, Greece, Turkey, Saudi Arabia and India, fit this criterion and are future growth markets for EfW and CSP systems.

Several CSP technologies are available for the hybridisation with EfW, such as parabolic trough, Fresnel, solar towers or dishes. Identifying the ideal technology is crucial and a variety of criteria have to be taken into consideration, such as land & water use, technology maturity and cost. CSP technologies in this paper were evaluated for feedwater heating, reheat steam and superheated steam meeting steam turbine requirements. Steam parameter considered range from 270-430°C.

CSP and EfW plants share similarities in terms of steam temperatures and capital investment. Steam temperatures of mature CSP technologies reach 440°C, which matches the steam temperatures of EfW plants well. Additionally, both technologies have high capital requirements and enabling them to share equipment, such as steam turbine, condenser, building infrastructure etc, will lead to specific cost reductions and make the hybrid plant concept more competitive.

Keywords: Energy from Waste, concentrating solar power, hybrid plants, Fresnel, multi-criteria decision making

1. Introduction

With electricity prices and demand typically being higher during the day in Australia [1] a CSP component attached to an EfW plant can provide additional capacity during these times while the EfW facility provides base-load power. This is particularly interesting for locations with high daytime ambient temperatures as they negatively affect the condenser performance which leads to a reduction in generation output. The hybrid system benefits from this configuration by providing more electricity to the grid during these economically attractive hours.

When hybridizing EfW plants with CSP a high DNI is essential. Typically, hybrid plants are viable in lower DNI areas than stand-alone CSP plants which enables them to move closer to load centers, avoid network costs and ensure fuel availability. The first Energy from Biomass (EfB)/CSP hybrid plant worldwide currently under construction in Spain proves these hybridization benefits, as it is located further north than any other CSP plant in Spain [2], [3].

For Australia, and other countries with a high DNI, the hybridisation of EfW with CSP technologies is promising to comply with landfill diversion targets and better align the capacity of power generation assets with demand profiles. EfW/CSP hybrid plants are likely to be niche solutions as several fuel resources have to be in one location and EfW plants typically have a smaller capacity, ≤35MWe.

2. CSP hybrid plant benefits

The main benefit of CSP hybrid over stand-alone CSP plants are immediate LCOE reductions of up to 28% [4]. Such reductions would reduce/eliminate the need for government incentives, allow plant suppliers and financiers to gain expertise, and are likely to accelerate the construction of CSP systems. The comparatively high LCOE of CSP is the key reason for its small contribution to global electricity supply.

Typically, renewable energy sources such as wind and solar suffer from poor capacity factors, 20-30% [5], compared to conventional fossil fuel plants, except for CSP with currently high cost thermal storage, AU$90/kWhth [6]. Hybrid plants have the ability to reliably provide electricity during the night, extended cloud coverage or DNI fluctuations, without thermal storage which is a significant benefit in terms of plant investment and complexity. Thermal storage systems could potentially be retrofitted at a later stage when costs reach the expected AU$22/kWhth by the end of this decade [6]. Additionally, CSP hybrid plants can follow daily electricity demand with the host plant operating constantly at design point and the CSP component satisfying the higher electricity demand during the day when electricity prices are economically more attractive.

Typically, CSP plants require a DNI >2,000kWh/m^2/year to be commercially viable. Due to the joint use of equipment, such as steam turbine, condenser etc, CSP/EfB hybrid plants can be considered for DNI areas >1,700kWh/m^2/year [7]. The first CSP/EfB hybrid plant near Barcelona verifies this assumption as it is the CSP installation furthest north in Spain. CSP/EfW hybrid plants could be build in even lower DNI areas as the low/negative fuel price for waste materials has a positive effect on the plants economic performance. DNI levels of >1,500kWh/m^2/year are considered acceptable. Moving CSP out of arid/semi desert regions closer to agricultural/urban regions expands potential CSP sites and enables access of back-up fuel resources, e.g. agricultural and urban waste materials.

Currently, many power plant operators in Australia and elsewhere are not familiar with CSP systems and are therefore likely to favor technologies, renewable or fossil, they know over CSP when deciding on new generation assets. CSP hybrid plants would allow them to use current staff while simultaneously up-skilling them to confidentially operate initially smaller but subsequently larger and larger CSP installations.

With CSP/EfW & EfB hybrid plants unlikely to exceed plant capacities of 60MWe such systems can be considered distributed generators that could be placed close to demand centers. This not only reduces transmission losses but also offers the chance to avoid/defer investment in transmission and distribution infrastructure, which are main drivers of current electricity prices rises. In Australia distribution infrastructure is expected to be responsible for 42% of the total electricity price increase from 2011-12 to 2013-14 and transmission 8% [8]. Moving CSP closer to load centers also increases chances for highly efficient combined heat and power applications.

3. Energy from Waste/biomass hybrid concepts

Principally, the CSP component of a hybrid plant can provide steam at different qualities. Low-temperature options include feedwater heating, mid-range temperature options include saturated steam into the high pressure boiler drum or steam into the cold reheat line, and the high-temperature option is superheated steam to the joint steam turbine, see Figure 1.

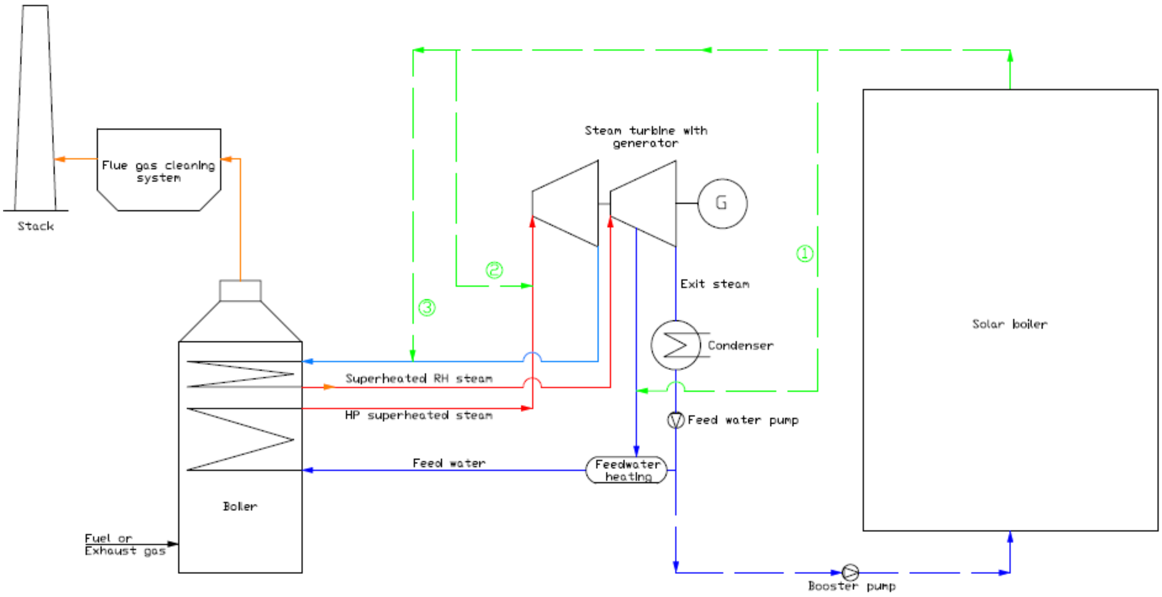

Figure 1: CSP integration options into an EfW plant; 1 = feedwater heating, 2 = cold reheat line, 3 = high pressure/temperature turbine steam

First concepts to pair biomass and waste materials with CSP were investigated at a high level in the mid 1980's with paraboloidal dish systems [9] but no plants were built. It took another 25 years before construction of the first commercial CSP/EfB hybrid plant, 25MWe [3], commenced ca 150km west of Barcelona, Spain [2]. To minimise risk the plant uses the mature parabolic trough technology with thermal oil [3]. The disadvantage of having the biomass system in the thermal oil loop (see Figure 2) is the lower steam temperature of 375°C compared to 450°C, which is technically possible with forestry and agricultural waste materials. Other parabolic trough concepts integrate the biomass system into the secondary water-steam cycle to increase plant efficiency (see Figure 2), e.g. 107MWe hybrid plant proposal at San Joaquin, US [10].

Currently, no CSP/EfW hybrid plants are under construction anywhere in the world but EfW steam temperatures, typically 380-440°C [11], match well with current CSP technologies, such as parabolic trough, Fresnel or solar tower. Some studies investigate the integration of Fresnel [11], [12] and parabolic trough systems in EfW plant [11], [13]. Concepts discussed include the use of CSP for air and feedwater heating [11] as well as the generation of identical steam parameters as the host plant using Fresnel [12] and parabolic trough systems [13], [14]. External EfW steam superheating using Fresnel is being investigated [14] but seems unlikely to be a reliable option for high-temperature steam supply. All of the concepts consider CSP steam temperatures <430°C.

The hybridisation of EfW with paraboloidal dish systems was briefly discussed in the past [9] while solar towers are currently being investigated for construction and demolition timber as well as RDF [15].

Some EfW plants are hybridized with combined cycle gas turbine (CCGT) plants. The EfW plants Moerdijk in the Netherlands [16], Mainz in Germany [17] and Bilbao in Spain [18] provide steam to the heat recovery steam generators of adjacent CCGT plants for further superheating. An EfW plant in Måbjerg, Denmark has taken a different approach using natural gas to further superheat the steam [19]. All these plants raise the final steam temperature from <430°C to >520°C, therewith increasing the overall conversion efficiency.

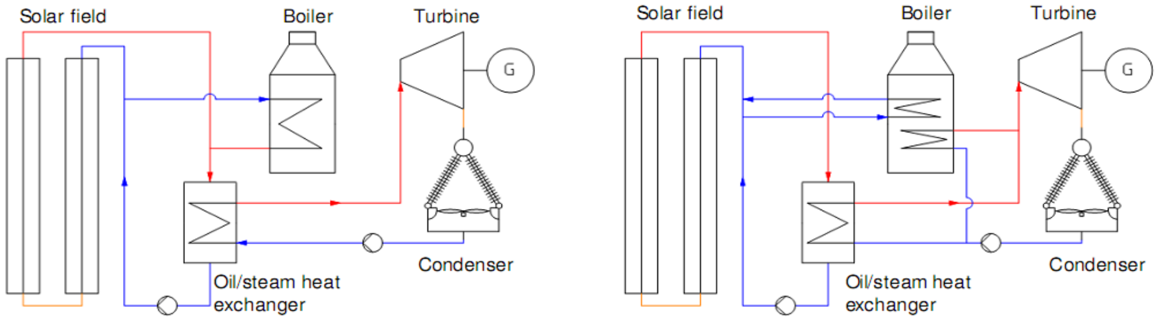

Figure 2: Simplified hybrid concept for the Termosolar project, Spain (left) and San Joaquin proposal, US (right)

4. Swanbank case study, Queensland, Australia

The Swanbank landfill at Ipswich, Queensland is owned and operated by Thiess Services Pty Ltd. The site is ideal for a new power station as it is an industrial zoned area with a long tradition in power generation, recently decommissioned 480MWe coal fired and one operating 385MWe CCGT power station.

With Ipswich being one of the fastest growing communities in Australia the proposed power plant could provide new local industries and residential areas in its vicinity with renewable and low-carbon intensity electricity, heating and cooling while creating long-term high value employment.

The landfill has the capability to ensure long term supply of wood waste, refuse derived fuel (RDF), landfill- and biogas for a 35.5MWe net power plant, EfW contribution 30.7MWe and CSP contribution 4.8MWe. Fuel availability is a significant benefit as the reliable supply from local sources is the main criteria for an EfW and EfB power station. Using the aforementioned fuels would defer ca 150,000t/a waste from landfill without sacrificing recycling efforts as only solid materials downstream a recycling process are used.

The proposed plant is modeled with Thermoflex Version 22.0.1, can generate up to 252,800MWh per year, see Table 1, and follow daily demand with its main fuels. It also has the potential to provide extra steam from the solar field during the day to increase the plant output when electricity demand/prices are high.

Peak net annual power output	252,800MWh
Net power output wood waste and RDF component	245,600MWh
Peak net power output of the CSP component	7,200MWh

Table 1: Maximum annual power plant electricity output

4.1. Plant concept

The Swanbank hybrid is designed to maximize plant efficiency. Due to a novel plant hybrid concept the power station achieves an electric net efficiency of 33.6% which is significantly higher than the 30% of other modern EfW plants, such as the significantly larger, 66MWe, EfW plant in Amsterdam, Netherlands [20].

The simplified technical concept of the Swanbank CSP/EfW hybrid plant is outlined in Figure 3. Upon waste arrival the fuel is sorted in the material recovery facility. Recyclable materials and waste destined for landfill leave the facility while the organic rich fraction, wood waste and RDF are suitable power plant feedstocks. Two third of the solid material used in the power station is wood waste, 12.5t/h, and the remaining third RDF, 6.25t/h. Up to 2,600m^3/h of bio- and landfill gas are required during peak capacity operation.

Wood waste and RDF are supplied to the boiler which is generating steam at 430°C and 90bar. The steam temperature is chosen to minimise high temperature corrosion issues inside the main boiler. The solar field is generating identical steam parameters as the main boiler and both steam flows are combined before entering an external superheater. The organic rich fraction of the waste material is digested in Thiess Services proprietary biocell technology [21] and the biogas, in combination with available landfill gas, is fired into an external superheater to further raise the steam temperature from 430°C to 530°C. External superheating of EfW steam has been realised at the EfW plant in Måbjerg, Denmark using natural gas [19].

The combined high pressure/temperature steam flow, up to 117t/h, enters one steam turbine. The turbine exit steam is condensed, using a water cooled condenser, and pumped back into the solid fuel boiler and solar field, thus closing the thermodynamic cycle. Flue gases are cleaned according to Australian emission limits using scrubbing and baghouse filter systems.

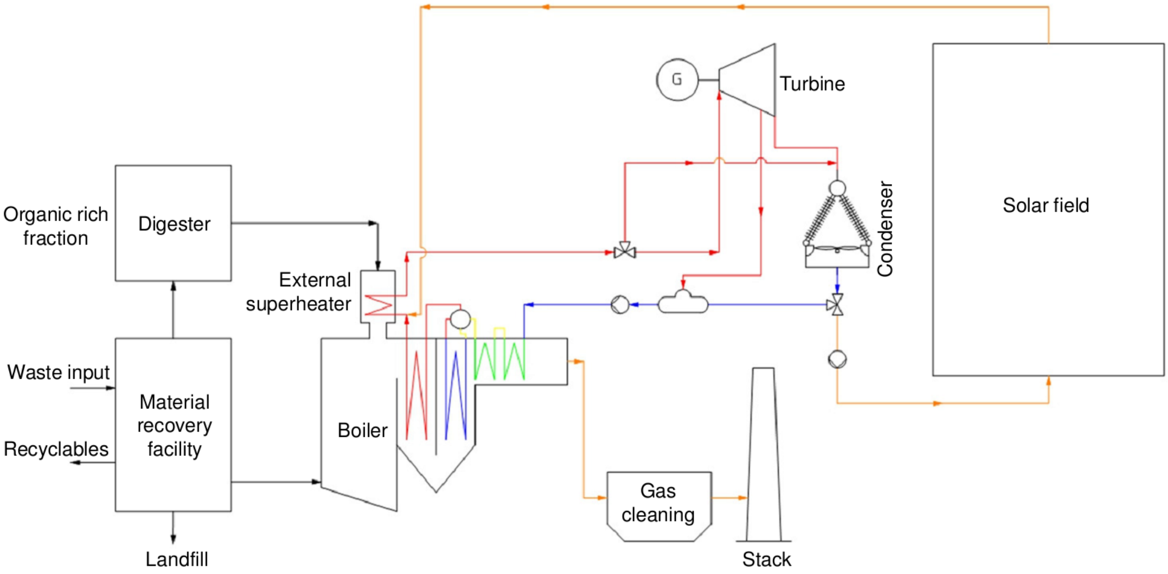

Figure 3: Simplified concept of a CSP / solid fuel hybrid plant with external superheating

4.2. Technology selection

Several CSP technologies are available for hybridisation with an EfW facility and in this assessment we considered the following:

- Parabolic trough; thermal oil (TO), direct steam generation (DSG) and molten salt (MS)
- Solar tower; molten salt (MS), direct steam generation (DSG) and air (A)
- Fresnel; saturated (Sat. St.) and superheated (Sup. St.) steam
- Paraboloidal dish; direct steam generation (DSG).

In July 2011 we organised a workshop at the University of Technology Sydney with 49 industry professionals with different expertise in the energy business (plant operators, technology provider, financiers and researcher) to identify the best CSP technologies to integrate into, amongst other, wood waste and RDF plants. The following steam temperatures scenarios were investigated:

- Live steam at 430degC to steam turbine,
- Steam at 300°C into the cold reheat line, and
- Steam at 270°C for feedwater heating.

To identify the best CSP technology for the Swanbank project we used the Analytical Hierarchy Process (AHP) as it allows the decomposition of a complex problem into several sub-problems, such as land use with levelised cost of electricity (LCOE), and provides a comprehensive and rational decision making framework [22]. The method is widely used in the research and industry world, including assessments comparing fossil fuels with renewable sources [23] and different CSP standalone technologies with each other [24].

The problem decomposition takes place by identifying criteria (main- and sub-criteria) relevant to the problem and organizing them in different levels of hierarchy. The AHP can use precise criteria data (quantitative information) as well as the personal judgments (qualitative information). Subsequently, quantitative and qualitative information can be merged to calculate the total score for each option. Four main criteria groups (feasibility, risk reduction, environmental impact reduction and LCOE) with several sub-criteria, such as land and cleaning water use, site gradient tolerance, technology maturity, peak efficiency, complexity, were chosen to cover the relevant aspects of the Swanbank multi-criteria decision problem.

We identified quantitative data for all criteria from literature as well as own calculations/modeling. These quantitative data were merged with qualitative data derived from the participant's individual rating of the main/sub-criteria importance. CSP technologies with the highest total score are the preferred options. To accommodate uncertainties in the input data a ±10% sensitivity is applied to all results. As seen in Figure 4 not all CSP technologies can achieve the steam temperatures required for the different scenarios. CSP technologies unable to produce the desired steam temperature were excluded from the assessment.

For the integration of a CSP component into the high pressure/temperature steam cycle of a wood waste/RDF host plant the Fresnel technology with superheated steam scores best, see Figure 4, and is therefore the chosen technology for the Swanbank project. The reasons for the good score of Fresnel systems providing superheated steam include the low cleaning water requirements through robotic cleaning of the flat mirror panels, and the compact solar field minimizing land use.

Fresnel (superheated steam) and parabolic troughs (thermal oil) systems would be the preferred options for cold reheat steam, while parabolic troughs (thermal oil) score best for feedwater heating followed by Fresnel (saturated steam). However, these options are not considered in the Swanbank case study as they would reduce the CSP contribution to the overall plant output compared to high pressure/temperature turbine steam.

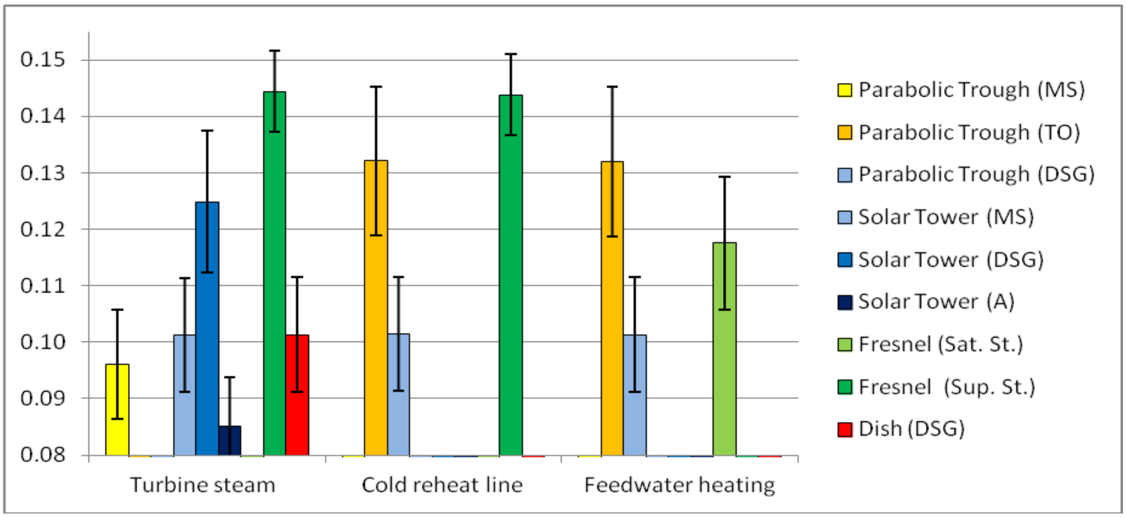

Figure 4: CSP technology selection for Swanbank hybrid plant

4.3. Plant siting and layout

As mentioned earlier CSP stand-alone plants typically require a DNI of >2,000kWh/m^2/a. However, through the joint use of equipment the site with a DNI of only 1,890kWh/m^2/a is still suitable for a CSP hybrid plant.

Space is constrained at Swanbank with the only possible site for a power plant south-west of the currently active landfill. A benefit of the location is the proximity to the current and new landfill which reduces material transport. The selected site is not level yet but earthworks to do this are not significant.

With the CSP component requiring the largest area its footprint is the limiting factor for the energy contribution. By arranging the EfW facility in the south, stretching from east to west, the area north of it is maximised for the CSP field, see Figure 5. To accommodate two Fresnel fields they have to be located north and south of the access road to the landfill. The fuel-exhaust gas flow of the power station is east to west, starting with the fuel processing facility, fuel storage, boiler, gas cleaning and stack. The steam turbine, auxiliary, workshop and cooling tower buildings are located south of the plant.

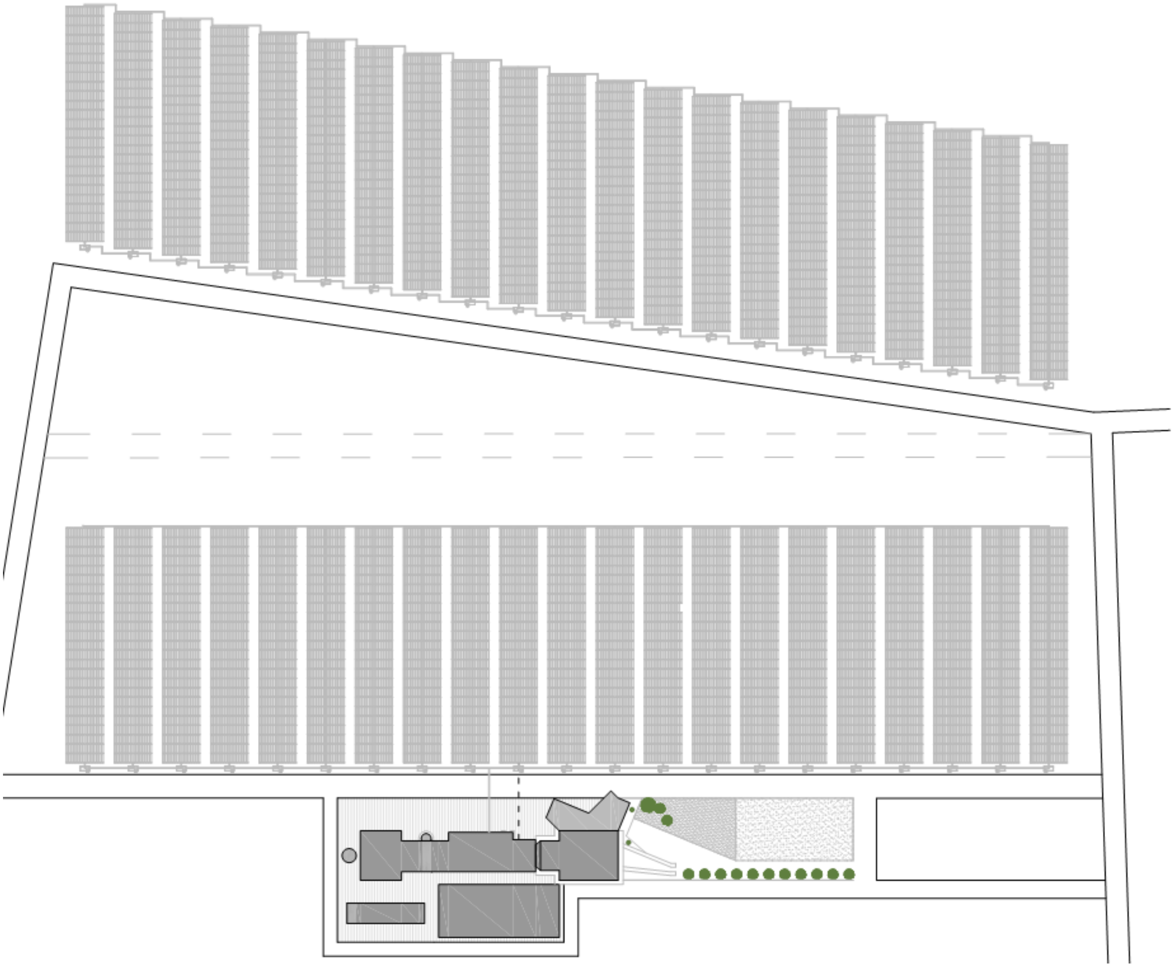

Figure 5: Plant layout of the Swanbank hybrid power station

Figure 6: Artist impressions of the proposed Swanbank hybrid power station[1]

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[1] Architecture proposal by Elena Vanz, PhD candidate in architecture and urban design at Melbourne School of Design, University of Melbourne

4.4. Economic analysis

The economic modeling is carried out with Thermoflex Version 22.0.1 and based on a plant life of 25 years. It includes capital as well as operational expenditures, e.g. personnel, fuel, water and residue disposal costs, as well as escalation rates for inflation, fuel, electricity, water and CO_2 prices. All assumptions are based on the plant commencing operation in 2017.

In the base case scenario the solid fuels are considered to have zero fuel cost while the assumed landfill and biogas price is AU$5/GJ. Depending on the future market developments for green waste and construction and demolition timber modeling was carried out for AU$-10, AU$10 and AU$20 per ton of solid fuel, Table 2.

The base case wholesale electricity price scenario assumes $45/MWh. With electricity prices currently increasing scenarios were modeled for electricity prices ranging from $30-$70/MWh, see Table 2.

The base case scenario is a renewable energy certificate (REC) price of $35/MWh. Due to fluctuations in the REC market scenarios were modeled for REC prices ranging from $30-$50/MWh, see Table 2.

The total investment for the power station is expected to be around AU$150-160m or 4.2-4.5m/MWe net. This price includes the fuel processing and storage facilities as well as grid connection. Considering the additional investment for the solar component the investment is in line with other EfW & EfB installations.

The levelised cost of electricity of the new installation is expected to be between AU$80-120/MWh, see Table 2. The final investment strongly depends on detailed negotiations with EPC plant contractors, expected CSP cost reductions in the next 3-4 years as well as fuel, carbon and renewable energy certificate pricing.

The modeling considered electricity generation only but the supply of process heat/cold to adjacent industries would strengthen the economic case and reduce the payback times of the different scenarios by up to 25%.

Except for scenario 1, see Table 2, the power station has a payback within its operational life but the scenario 2 and the base case scenario are not particularly attractive to institutional investors without other financial incentives. It is obvious that the electricity price agreed in a power purchase agreement has a significant impact on the plant's commercial viability. The fuel prices are relevant too but to a significantly lesser extent.

Scenarios	**Solid fuel price in $/t**	**Electricity in $/MWh**[2]	**Payback in years**
Scenario 1	20.00	60.00	>25.0
Scenario 2	10.00	100.00	14.5
Base scenario	0.00	80.00	15.1
Scenario 3	0.00	100.00	13.3
Scenario 4	0.00	120.00	10.6
Scenario 5	-10.00	100.00	12.3
Scenario 6	-10.00	120.00	9.9

Table 2: Economic viability of the hybrid power plant for different fuel and electricity price scenarios

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[2] Includes wholesale and renewable energy certificate prices

5. Conclusion

The hybridization of CSP with non-conventional fuels is likely to be a niche market compared to natural gas or coal hybrid systems but allows, subject to waste material composition, renewable base-load power generation. Only waste materials downstream a recycling process should be considered for such plant concepts.

All the individual components required for the Swanbank CSP/EfW hybrid project are proven with reference plants in operation using wood waste and RDF fired boilers, Fresnel systems, external steam superheating, and bio- / landfill gas combustion. The combination of the individual components is new but manageable with experienced project partners and modern power plant engineering tools.

The Swanbank site is ideal for such a concept as the landfill ensures fuel supply over the operational lifetime of the plant, the CSP system provides additional power during high electricity demand/price times and staff from the recently decommissioned coal fired power station could be recruited to operate the new facility. Due to the joint use of plant equipment the LCOE are competitive compared to other forms of renewable energy and the concept demonstration could trigger the development of similar projects in Australia and overseas.

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References

[1] S. Lekovic, P. Priftakis, K. Donoghue, T. Rigzin, S. Cole, B. Pryor, and K. Simic, “electricity gas australia 2011,” Energy Supply Association of Australia, Melbourne, Australia, 2011.

[2] Abantia, “The installation of the solar field Termosolar Borges, the first plant to combine thermal and biomass, has started,” 2011. [Online]. Available: www.abantia.com/noticias-prensa/en_noticias/28/the-installation-of-the-solar-field-termosolar-borges-the-first-plant-to-combine-thermal-and-biomass-has-started.

[3] A. Cot, A. Amettler, J. Vall-Llovera, J. Aguilo, and J. M. Arque, “Termosolar Borges: A Thermosolar Hybrid Plant with Biomass,” in *Third International Symposium on Energy from Biomass and Waste*, 2010.

[4] C. S. Turchi and M. Erbes, “Gas Turbine / Solar Parabolic Trough Hybrid Designs,” *ASME TurboExpo 2011*. Vancouver, Canada, 2011.

[5] P. Hearps and D. McConnel, “Renewable Energy Technology Cost Review,” Melbourne Energy Institute, Melbourne, Australia, 2011.

[6] J. Hinkley, B. Curtin, J. Hayward, A. Wonhaus, R. Boyd, C. Grima, A. Tadros, R. Hall, K. Naicker, and A. Mikhail, “Concentrating solar power - drivers and opportunities for cost-competitive electricity,” CSIRO & Aurecon Australia Pty Ltd, Sydney, Australia, 2011.

[7] Á. Pérez and N. Torres, “Solar Parabolic Trough – Biomass Hybrid Plants: A Cost – Efficient Concept Suitable For Places In Low Irradiation Conditions,” in *SolarPaces Conference 2010*, 2010.

[8] Australian Energy Market Commission, “Possible Future Retail Electricity Price Movements: 1 July 2011 to 30 June 2014, Final Report,” Sydney, 2011.

[9] C. F. McDonald, “A hybrid solar closed-cycle gas turbine combined heat and power plant concept to meet the continuous total energy needs of a small community,” *Journal of Heat Recovery Systems*, vol. 6, no. 5, pp. 399–419, 1986.

[10] California Energy Comission, “San Joaquin Solar 1 & 2 Power Plant Licensing Case.” Sacramento, California, 2008.

[11] H. Spliethoff, N. Kaeding, M. Murer, E. Alonso-Herranz, and O. Gohlke, “Combining Energy from Waste and Concentrated Solar Power: New Solutions for Sustainable Energy Generation,” in *International Solid Waste Association Conference 2010*, 2010.

[12] M. Rojas, U. Hellwig, J. H. Peterseim, and J. Harding, “Combining solar thermal power systems with solid fuels in new plants,” in *SolarPACES*, 2010.

[13] L. Schnatbaum-Laumann, “Biomass Utilization for Co Firing in Parabolic Trough Power Plants,” *SolarPACES 2009*. Berlin, Germany, 2009.

[14] N. Kaeding, “Hybridkraftwerk Solar/Abfall: Erstellung und Beurteilung von Konzepten,” Technische Universitaet Muenchen, Munich, Germany, 2010.

[15] J. H. Peterseim, “Biomass/CSP Hybrid Plants,” in *Bioenergy Australia 2011 Conference*, 2011.

[16] J. Toebes and M. Beker, “External steam input and process steam output at the Moerdijk (Netherlands) combined-cycle plant,” *VGB POWERTECH*, vol. 8, no. 7, Essen, Germany, pp. 21–27, 1998.

[17] Entsorgungsgesellschaft Mainz mbH, “The Mainz Waste-to-Energy Plant: Exceptionally reliable and environmentally sound waste disposal,” 2008. [Online]. Available: www.mhkw-mainz.de/downloads/EGM_infobro3_eng_20.pdf.

[18] S. G. Ribeiro and T. Kimberlin, “High Efficiency Waste to Energy Power Plants Combining Municipal Solid Waste and Natural Gas or Ethanol,” in *18th Annual North American Waste-to-Energy Conference*, 2010.

[19] E. J. Andersen, F. Oksen, and J. V. Olesen, “Power plant Holstebro / Struer with separately fired superheater,” in *ERK licensee conference*, 1992, p. 20.

[20] City of Amsterdam Afval Energie Bedrijf and C. of A. Afval Energie Bedrijf, “Value from Waste; Waste Fired Power Plant - The new standard for recovery of sustainable energy, metals and building materials from urban waste,” City of Amsterdam, Netherlands, 2006.

[21] W. P. Clarke, “Reusable Landfill Biocells for Rapidly Degrading the Organic Fraction of Municipal Solid Waste,” in *EcoForum 2012*, 2012.

[22] E. Triantaphyllou, *Multi-Criteria Decision Making Methods: A Comparative Study*. Dordrecht, The Netherlands: Kluwer Academic Publishers, 2000.

[23] B. A. Akash, R. Mamlook, and M. S. Mohsen, “Multi-criteria selection of electric power plants using analytical hierarchy process,” *Electric Power Systems Research*, vol. 52, no. 1, pp. 29–35, 1999.

[24] J. D. Nixon, P. K. Dey, and P. A. Davies, “Which is the best solar thermal collection technology for electricity generation in north-west India? Evaluation of options using the analytical hierarchy process,” *Energy*, vol. 35, no. 12, pp. 5230–5240, 2010.